Advanced Multi-Moment Microphysics for Precipitation and Tropical Cyclone Forecast Improvement within COAMPS

PI: Ming Xue
Center for Analysis and Prediction of Storms, University of Oklahoma
National Weather Center, Suite 2500
120 David Boren Blvd, Norman OK 73072, USA
Phone: (405) 325 6037 fax: (405) 3257614 email: **mxue@ou.edu**
Co-PI: Fanyou Kong

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LONG-TERM GOALS

The first major focus of this project is to implement and test a microphysics scheme capable of predicting up to three moments (total number concentration, mass, and the 6th-moment reflectivity factor) of hydrometeor hydrometeor particle size distributions (PSDs) inside the Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). After being implemented within the COAMPS, the scheme will be applied for the first time to tropical cyclone (TC) prediction, and to continental-scale severe weather prediction. The results will be verified against detailed in-situ and remote-sensing observations.

The second major focus is to develop interface software to bring the COAMPS into the multi-model multi-physics mesoscale/storm-scale ensemble prediction framework of CAPS (Xue et al. 2010), so that it can be run in realtime, at 1 to 4 km resolutions, for continental-US (CONUS) sized domains, side by side with three other state-of-the-art mesoscale models (WRF-ARW, WRF-NMM and ARPS). By using a common set of initial and boundary conditions, we will be able to identify the strengths, weaknesses and potential systematic biases of individual models, and understand the differences and commonalities of physics packages within these models and their performance. The findings will be used to guide the improvement to the COAMPS model. The framework will also be used to systematically test the performance of the multi-moment schemes implemented within COAMPS.

OBJECTIVES

The research efforts to be carried out in this project are synergistic with a recently funded project by the Office of Naval Research (ONR) through the Defense EPSCOR program. The latter focuses on the prediction and predictability of TCs through advanced ensemble-based data assimilation. This project complements the DEPSCOR project to together address the initial data (data assimilation), model improvement, model verification, ensemble/probabilistic forecasting issues, and the understanding of TC predictability. All of these aspects are of great interest to the Navy's research, development and operations.

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The research efforts serve to fill a number of R&D gaps of the Navy, DoD as well as NOAA's weather forecasting needs. In fact, it addresses our nation's priority need for significantly improved hurricane intensity forecast (NSB 2007). The research in general will accelerate our nation's capability in more accurately predicting highly-variable hurricane intensity, thereby potentially reducing hurricane-related losses through better preparedness and response, and reduction in the uncertainty in track and intensity forecasts that could directly translate into huge economic savings. The project will directly contribute to Navy's goal of reducing TC structure and intensity prediction error by 50% within a decade. The software developed within this project has a direct path of transition to Navy's operations.

APPROACH

After being implemented within the COAMPS, the multi-moment microphysics scheme will be applied to TC prediction, and to continental-scale severe weather prediction. The results will be verified against detailed in-situ and remote-sensing observations. With COAMPS being implemented at part of CAPS's multi-model ensemble system, it will be run initially during the Hazardous Weather Testbed (HWT, Weiss et al. 2010) Spring Experiment period, over the continental US domain, so as to take advantage of the vast volume of observational data that can provide accurate initial conditions and information for detailed verification. It will also allow us to leverage the NOAA-supported realtime storm-scale ensemble forecast experiments conducted by CAPS. Later on, we also plan to apply the multi-model ensemble system to selected TC cases, and evaluate the value and benefit of the multi-model ensemble system for improving the reliability and sharpness of TC probabilistic forecasting. These cases will be selected from Tropical Cyclone Structure-2008 (TCS-08, Elsberry et al. 2008) field campaign, the tropical storm season of 2010 (e.g., from PREDICT , Majumdar and Torn 2011), and from a future TCS field campaign.

WORK COMPLETED

We received funding for this project in June 2010. We report in the following progress we have made so far. We mention that we have obtained a copy of the COAMPS code, and are developing an interface for it to be incooperated into our multi-model ensemble system, according to our proposal plan.

1. Forecast sensity of Hurricane Ike (2008) to microphysics schemes

As an initial effort studying microphysics effects on TC prediction, we performed a number of experiments examining the forecast sensitivity to microphysics schemes. Under the support of our ONR DEPSCOR (N00014-10-1-0133) grant, an EnKF data assimilation study was carried out where Hurricane Ike (2008) was initialized by assimilating coastal Doppler radar data. Good predictions of the intensity, structure and track of Ike near and after landfall were obtained. A set of forecasts was produced starting from the EnKF ensemble analyses, and/or using different microphysics schemes. The goal was to examine how microphysics schemes affect the prediction of a landfalling hurricane, relative to the effects of initial condition uncertainties.

2. Realtime convection-resolving-resolution prediction of Atlantic hurricanes in fall 2011 using GFS and gloal EnKF initial conditions

From late August through early November, the CAPS group produced experimental, twice daily (00 and 12 UTC), 48-hour-long, realtime forecasts at 4-km resolution, over a 7200x3600 km domain

covering central and western Atlantic, in order to capture hurricanes from their genesis through demise or extra-tropical transition stages. Two sets of forecast were made, one initialized from NCEP GFS analyses and one from global EnKF analyses produced by Dr. Jeff Whitaker of ESRL (Hamill et al. 2010). The forecasts are posted in realtime at http://forecast.caps.ou.edu/hurricane.html with additional products available at http://forecast.caps.ou.edu/wx/p (enter through the daily calendar). Through these forecasts, we intend to study the benefit of a single large grid with convection-resolving resolution in improving hurricane intensity forecast, and the potential benefit of EnKF data assimilation relative to operational GSI 3DVAR system. We also intend to analyze the prediction data sets for the understanding of physical processes, including the role of convection in TC genesis.

RESULTS

1. Forecast sensitivity of Hurricane Ike (2008) to microphysics schemes

Three 4-member ensemble forecasts were conducted, with initial perturbations or microphysical parameterization perturbations or both. When the initial condition perturbations and the microphysical schemes perturbations are combined together in Exp4FULL, the intensity spread is larger than Exp4PERT, with initial perturbations only, and Exp4PHYS, with microphysical parameterization perturbations only, after 1200 UTC (Fig. 1). The growth rate of intensity spread in Exp4FULL is close to Exp4PHYS, demonstrating a greater sensitivity of the intensity forecast to microphysics uncertainties than the initial condition sensitivities as represented by the EnKF ensemble analyses. For most of the forecast times, the spread of Exp4FULL is always smaller than the sum of the spreads of Exp4PERT and Exp4PHYS due to the nonlinear effects.

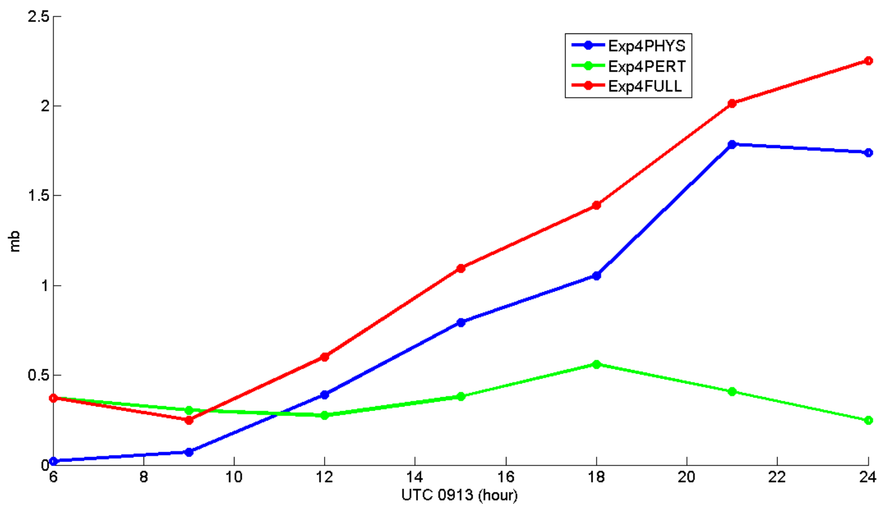


Fig. 1. The spread of intensity forecasts for Exp4PHYS (blue, microphysical parameterization perturbations only), Exp4PERT (green, initial condition perturbations only) and Exp4FULL (red, both microphysical parameterization and initial condition perturbations).

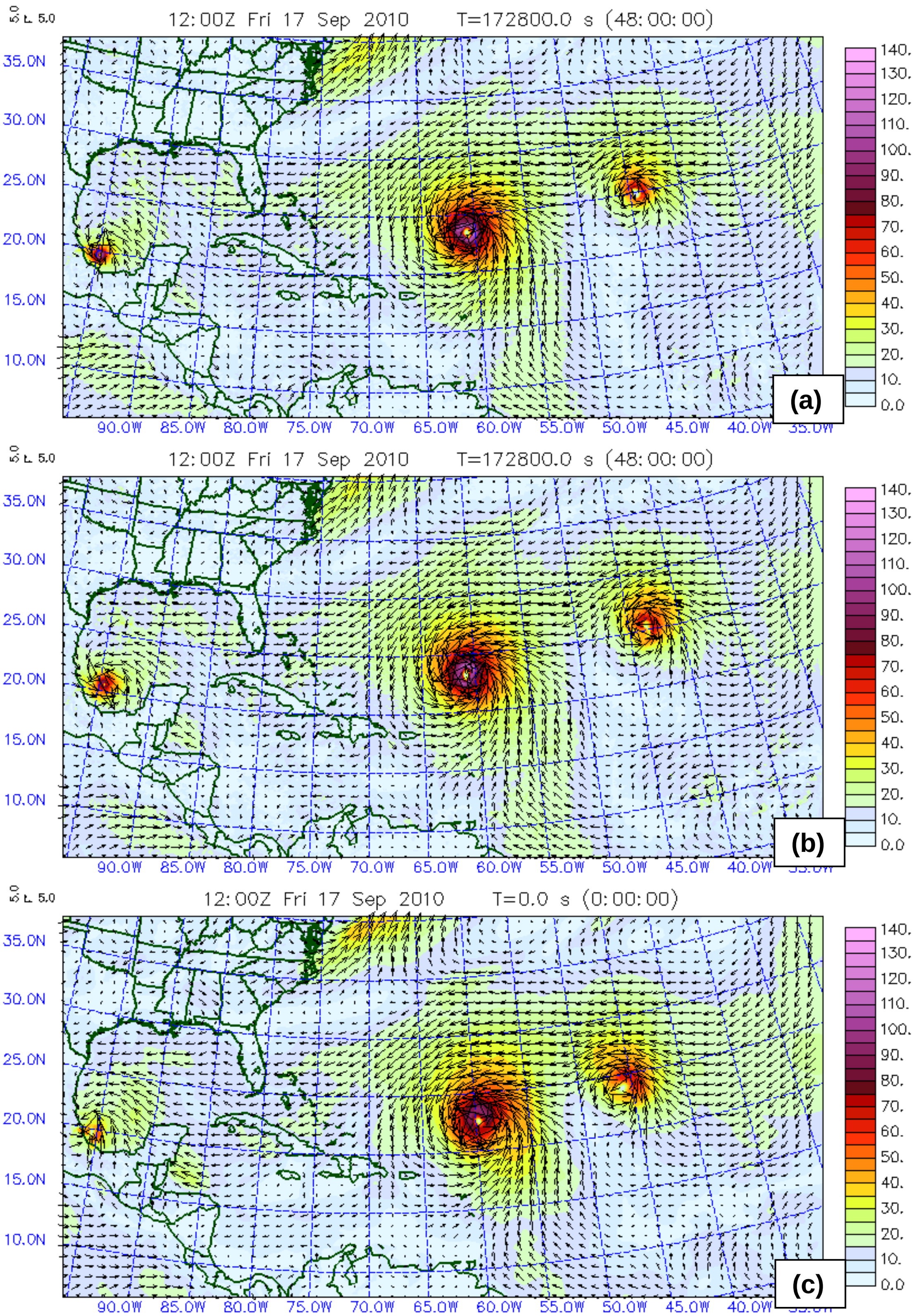


Fig. 2. Surface wind speed (shaded) and wind vectors from 48 hour forecasts using global EnKF analysis produced by ESRL (a) and NCEP GFS analysis (b), at 4 km grid resolution, and the GFS analysis valid at the same time. Hurricanes Karl, Igor, and Julia are lined up from west to east.

3. Realtime convection-resolving-resolution prediction of Atlantic hurricanes in fall 2011 using GFS and gloal EnKF initial conditions

Since our realtime forecasts are still ongoing (extending into November), only preliminary evaluation has been performed on the forecasts so far. Fig. 2 shows example 48-hour forecasts of surface wind speed (shaded) and wind vectors using global EnKF analysis produced by ESRL (Fig. 2 a) and NCEP GFS analysis (Fig. 2b) as initial conditions respectively, as compared to the GFS analysis valid at the same time. As can be seen, three TCs/hurricanes, namely, Karl, Igor, and Julia (from west to east), are present within the model domain at this time. The intensities of these TCs are predicted well in both cases, with those from the EnKF analysis being somewhat stronger especially with Karl. The track forecast errors using EnKF initial condition appear to be smaller. Further quantitative verifications on the forecasts will be performed.

Among the 2010 Atlantic hurricanes, Earl was most interesting. It was a long-lived tropical cyclone which became the first major hurricane to threaten New England since 1991. It reached Category 4 intensity during its life cycle (Fig. 3).

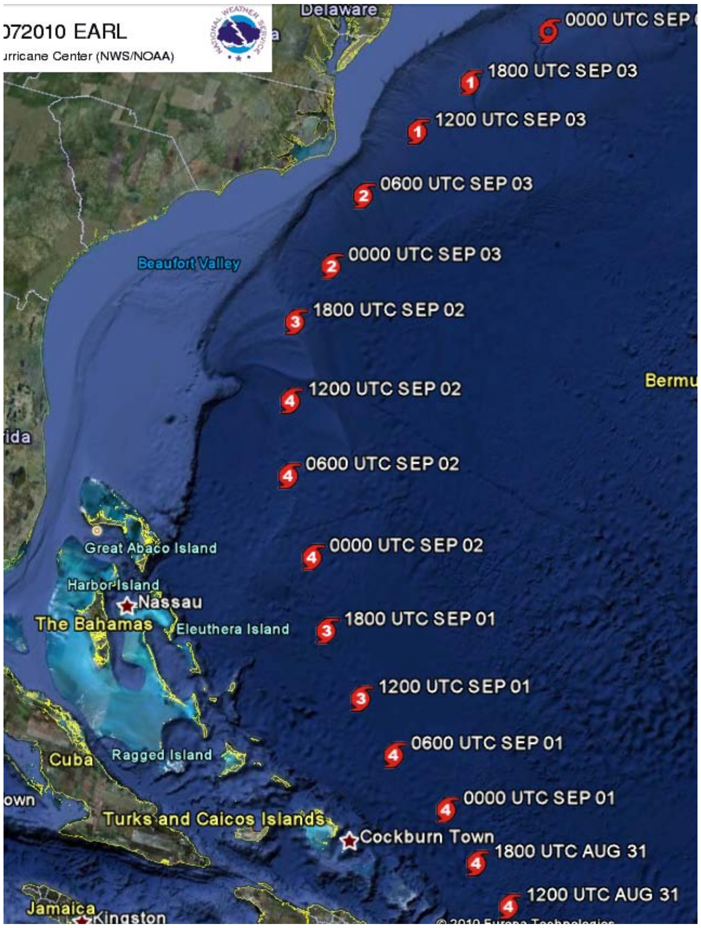
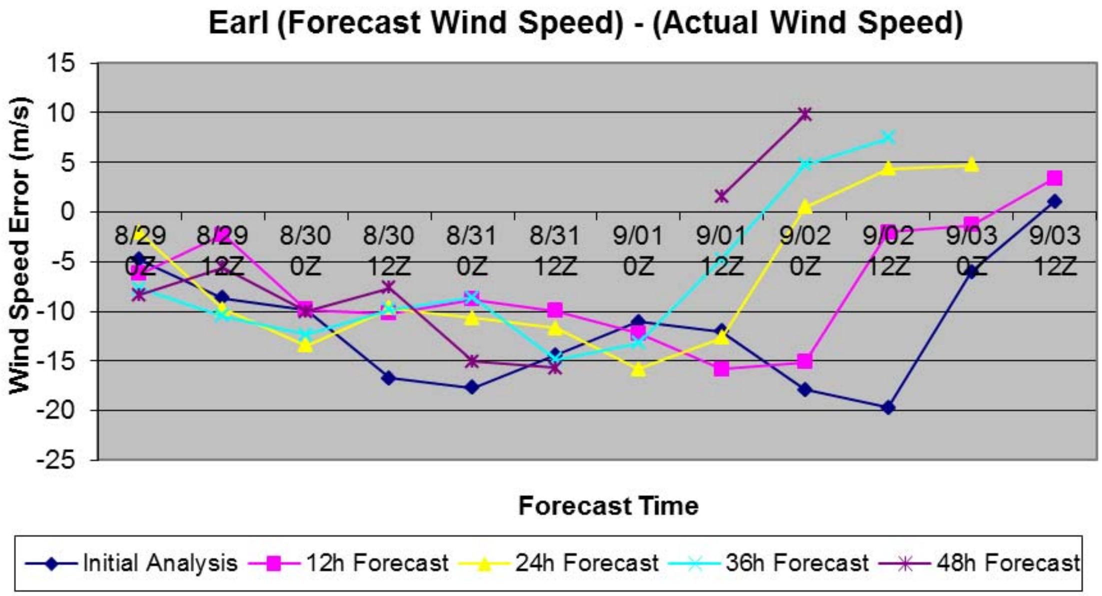


Fig. 3. The intesnity and track of Hurricane Earl (2010).



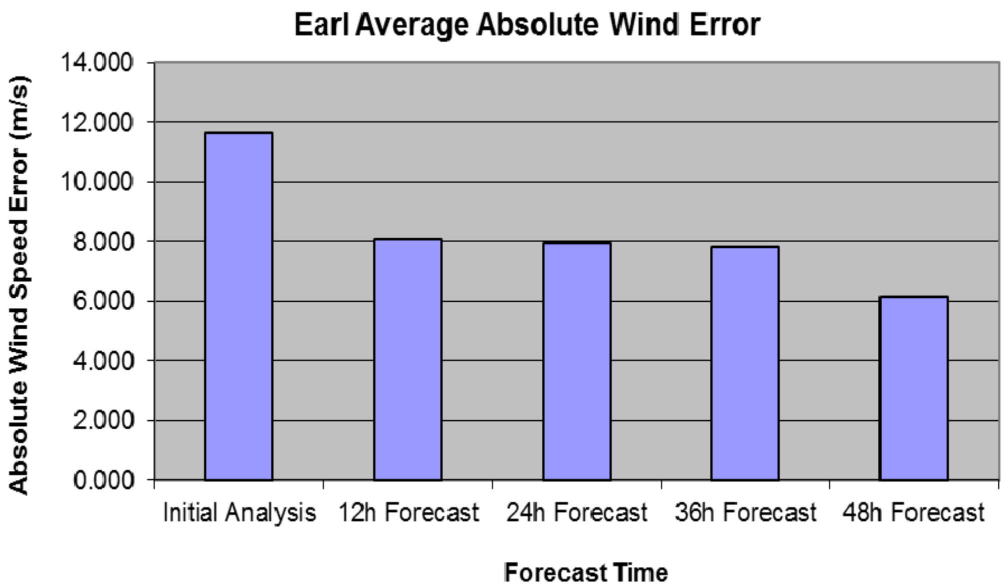


Fig. 4. Maximum surface wind speed errors for Hurricane Earl (2010) forecasts of different ranges starting at the times indicated by the horizontal axis (upper panel), and (lower panel) the absolute wind speed errors for different forecast ranges averaged over forecasts starting at different times. These forecasts used GFS initial and boundary conditions.

Fig. 4 shows that the errors in the maximum surface wind speed forecast are generally less than 8 m s^{-1}, which is very good. The error is generally associated with under predictions. What is perhaps surprising at first glance is that the average wind speed error decreases with increasing forecast range. This is because of the under-estimation of wind speed in the GFS analyses that were used as our initial conditions. Given the 4 km grid resolution, the hurricane vortex was able to spin up in the model forecast, reducing the forecast error over time. This is somewhat similar to the precipitation spin-up in numerical weather prediction models where the precipitation systems are not well represented in the initial conditions.

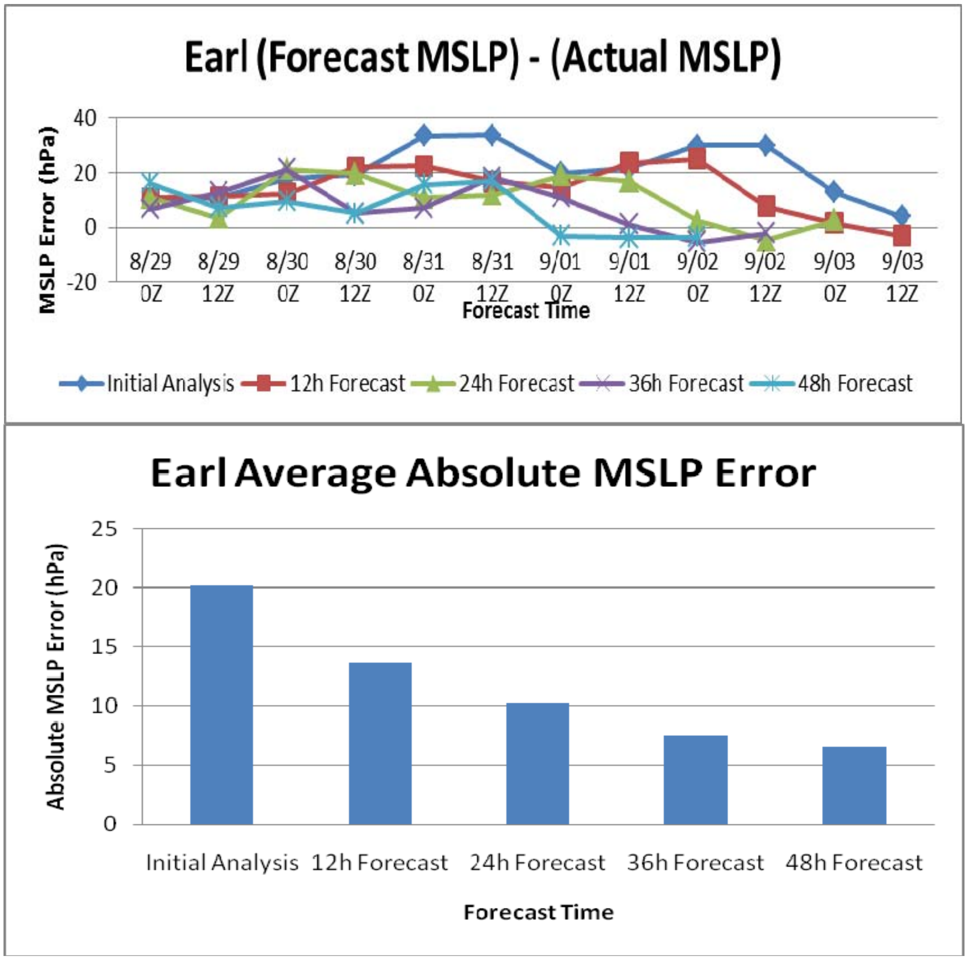


Fig. 5. As Fig. 4 but for minimum mean sea-level pressure (MSLP) forecast errors.

Fig. 5 shows that the errors in MSLP forecasts are generally less than 15 mb. Again the forecast error decreases with forecast range. The forecast model is able to spin up the model hurricane to reach better intensity forecasts at later times. The track errors are between 40 and 90 km, for forecasts ranging from 12 to 48 hours. For track, the average error increases with forecast range, as one would expect. The initial hurricane location was analyzed rather accurately within the GFS initial conditions, with the mean error being a little over 10 km. This was due to the use of vortex re-allocation within the GFS system. In the future, we will complete the intensity and track verifications for all hurricane cases, and compare the GFS- and EnKF-initialized forecasts.

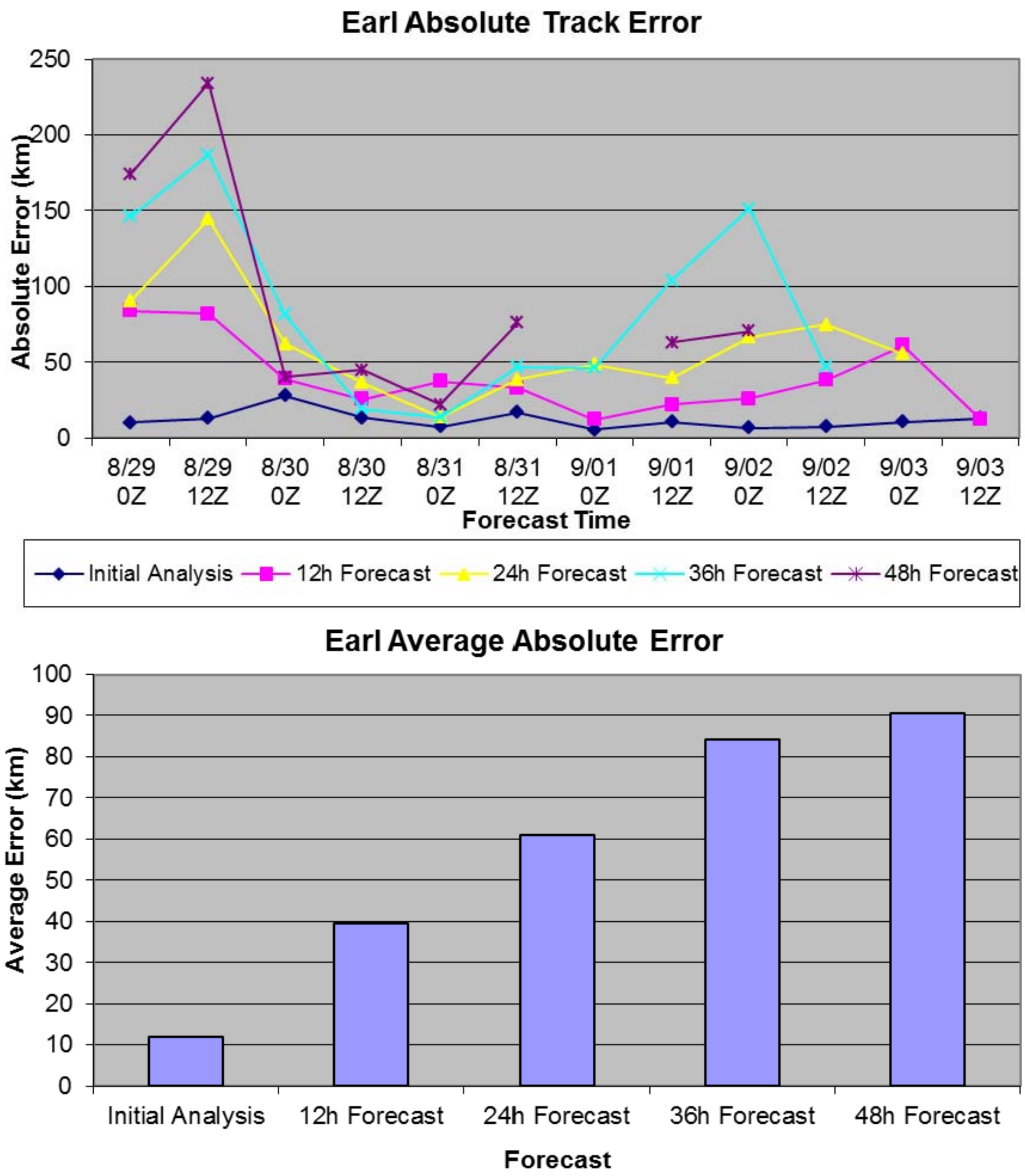


Fig. 6. As Fig. 4 but for track forecast errors.

IMPACT/APPLICATIONS

Through collaborations with scientits (Drs. Allen Zhao, Yi Jin, Hao Jin, Melenda Peng) at Naval Research Lab at Moneterey, new microphysics and ensemble forecasting capabilities developed within this project for the COAMPS will be transitioned into Navy’s research and operations. Physical understanding gained on the structures and processes with TCs will help us improve observing and prediction systems for TCs.

RELATED PROJECTS

This project is complemetary to our ONR DEPSCOR project “Prediction and Predictability of Tropical Cyclones over Oceanic and Coastal Regions and Advanced Assimilation of Radar and Satellite Data for the Navy Coupled Ocean-Atmosphere Mesoscale Prediction System” (N00014-10-1-0133) led by the same PI.

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